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Integrated Low-Loss Planar Goubau Lines on Glass Interposer for 6G Wireless Applications

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***Abstract* — This paper presents the design, fabrication, and measurement of low-loss planar Goubau lines (PGL) integrated onto thin glass interposer for D-band (110 GHz – 170 GHz) applications. The core material is 200 µm AGC ENA1 glass with 15 µm Ajinomoto Build-up Films (ABF) GL102 laminated on both sides. CPW-PGL launchers are designed to excite the supported surface wave mode. PGLs with different lengths are fabricated to extract the loss per millimeter. The measured results show around 0.32 dB/mm loss at 140 GHz. The comparison between PGL and other interconnects on glass substrate for D-band application is presented.**

***Keywords* — D-band, glass interposer, interconnects, planar Goubau line, surface wave.**

I. Introduction

With high bandwidth availability, D-band (110 GHz to 170 GHz) shows great potential for the next generation of wireless communication (6G). However, system integration in D-band poses multiple challenges. From fabrication and mechanical aspects, with the miniaturization as the frequency goes higher, fine pitch lines and high precision vertical interconnects are required. And mechanical stability of the package plays a more important role for miniaturized structures. From the thermal aspect, more heat will be generated per unit area due to the decrease of the power efficiency as the frequency goes higher. From the electrical aspect, the loss of commonly used interconnects on packages like a microstrip line or CPW increases as the frequency goes higher.

Glass-based package is a promising solution for high frequency applications above 100 GHz. Fine-feature sizes can be realized on glass package [1]. With tailored coefficient of thermal expansion (CTE) and high dimensional stability, glass can be a good material from mechanical standpoint. For thermal management, the glass can still provide higher thermal conductivity compared with an organic package. And for the electrical performance, glass-based package can support interconnects with comparable loss with high resistivity Si while it costs much less. Above all, the glass package has great potential for high frequency applications.

D-band interconnects, namely microstrip line, coplanar waveguide (CPW), and substrate integrated waveguide (SIW) are implemented on glass package [2][3]. However, with two conductors, these structures introduce more conductor-associated losses with higher operating frequencies [4]. This feature also makes these structures sensitive to surface roughness of the metal layers. Moreover, as the line pitch gets narrower, the crosstalk of microstrip lines and CPWs becomes more severe. SIW doesn't have the problem from crosstalk, but it increases the complexity for fabrication. Compared with these structures, planar Goubau line (PGL) only contains single conductor, which can reduce the conductor-associated loss and the fabrication complexity. The fundamental mode of PGL is surface wave mode, which has been demonstrated to have lower crosstalk by other single-wire transmission lines [5]. This paper demonstrates the PGL on glass substrate for D-band application which is a promising alternative for interconnects at D-band.

II. Design and Fabrication

The substrate stack-up of the PGL is shown in Fig. 1a. A glass substrate (AGC ENA1) with a thickness of 200 µm is used for good surface wave launching. A 15 µm Ajinomoto Build-up Film (ABF) GL102 dielectric layer is laminated in between the glass substrate and the metal layer to increase the adhesion of the metal. The PGL is implemented on the top metal layer. In order to increase the mechanical balance of the entire stack-up, same dielectric layer and metal layer are built on the other side. For the dielectric constant (Dk) and loss tangent (Df) of the glass AGC ENA1 and ABF GL102, similar stack-up has been characterized [2] which shows a Dk of around 4.6 for the entire stack-up in D-band. The loss tangent values of 0.009, 0.012 and 0.015 at 120 GHz, 140 GHz, and 160 GHz [3] were used for simulation. This stack-up of the PGL can be integrated with other structures on glass-based package like patch antenna arrays, substrate integrated waveguides and chip-embedded packages, which shows high ability of integration.

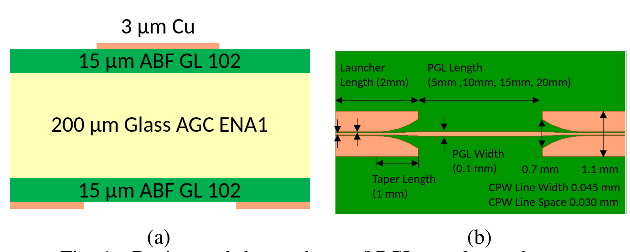

Fig. 1. Design and the stack-up of PGL on glass substrate

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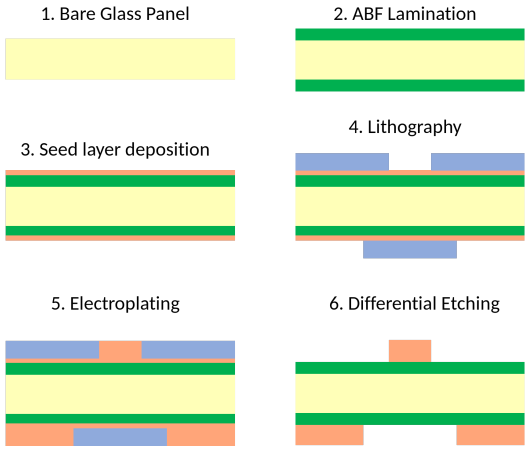
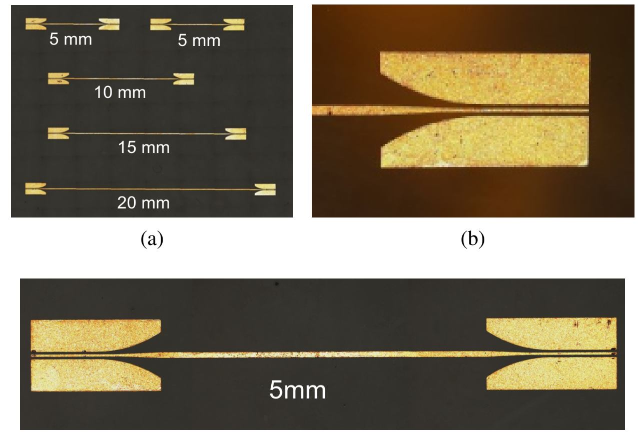


Fig. 2. Process flow of PGL on glass substrate



(a) (b)

(c)

Fig. 3. Fabricated PGLs on glass substrate (a) PGLs with different lengths (b) CPW-PGL launcher (c) PGL with 5 mm length

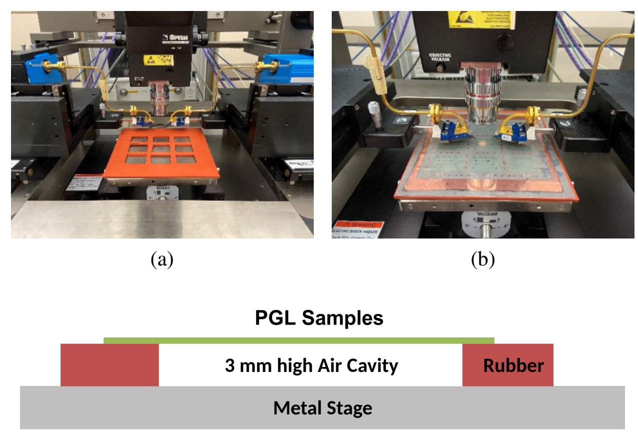
PGL uses single metal strip to guide the surface wave. CPW-fed tapered launchers are used [6] to excite the surface wave mode on the planar conductor strip. The dimension of the CPW feeding lines is consistent with the 75 µm D-band probe pitch (Cascade Infinity Probe). The length of the launcher, width of PGL and the thickness of the glass substrate are optimized by Ansys HFSS to maximize the surface wave launching. The dimension of the PGL and the launchers are shown in Fig. 1b. PGLs with different lengths (5 mm, 10 mm, 15 mm, 20 mm) were designed to extract the loss from PGLs and exclude the effect from the launcher.

The Standard Semi-Additive Patterning (SAP) process was used for the fabrication [7] as shown in Fig. 2. First the 15 µm ABF GL102 layers were laminated on both sides of the glass. Then around 300 nm Cu seed layers were deposited on the surface of the ABF using electroless Cu plating. A 15 µm thick negative dry-film photoresist was laminated on the Cu seed layer. After lithography, the Cu was electroplated to 3 µm. Finally the photoresist was removed, and the seed layer was etched using differential etching. Without the need for via fabrication and accurate alignment between layers, this structure greatly reduces the fabrication complexity and increases the yield compared with microstrip lines and SIWs. The fabricated PGLs are shown in Fig. 3. The structures were examined using the Zeta Optical Profiler. For some of the structures, less than 5 µm shrinkage of the Cu structures was detected which is from the over exposure during lithography and over etching during Cu seed layer etching.

III. Measurement and Results

A. *Measurement setup for PGL*

The measurement setup for the PGLs on the glass substrate is shown in Fig. 4. To measure the surface wave structures, the effect from the metal stage on the probe station needs to be eliminated. The fabricated glass panel was lifted from the metal stage using a 3 mm thick rubber sheet with cavities. This height is more than one free space wavelength at 110 GHz, so the effect from metal stage was reduced to a very low level in D-band which is confirmed by simulation. Agilent vector network analyzer (VNA) E8361C along with D-band frequency extenders (V06VNA2) were used. The D-band probes for measurement are Cascade Infinity probes 170-S-GSG-75-BT with 75 µm pitch. Line-reflect-reflect-match (LRRM) calibration was performed to eliminate the effects from cables, waveguides, and probes.



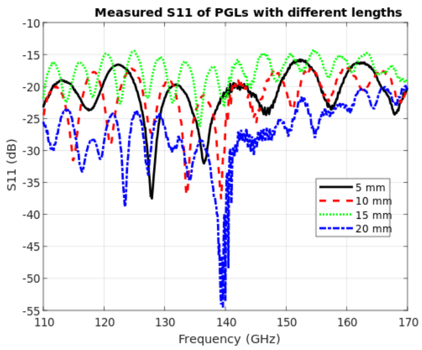
(a) (b)

(c)

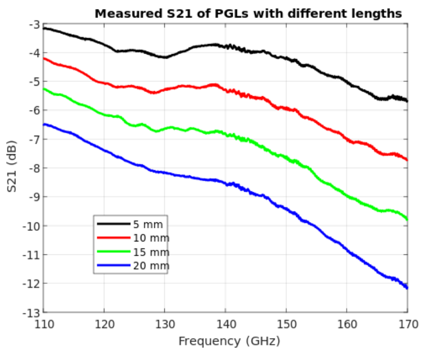
Fig. 4. Setup for PGL measurement (a) Rubber sheet with cavities on the probe station (b) Substrate lifted by the rubber sheet (c) Measurement setup to eliminate the effect from metal stage

B. *Measurement and simulation results of PGL*

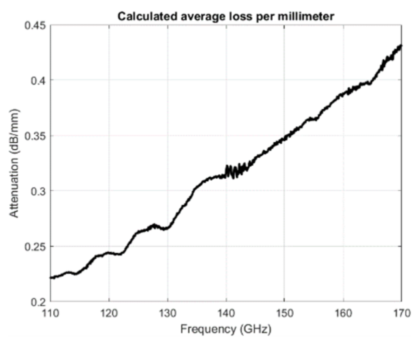
The measured results for PGL from 5 mm to 20 mm are shown in Fig. 5a and Fig. 5b. The scattering parameters of the fabricated PGLs were measured from 110 GHz to 170 GHz (D-band). The loss per unit length and the loss from the launcher can be extracted by calculating the loss difference for every 5 mm PGL length increments. The extracted loss of the PGL per millimeter is shown as Fig. 5c. The calculated result shows less than 1.2 dB loss per launcher at 140 GHz.



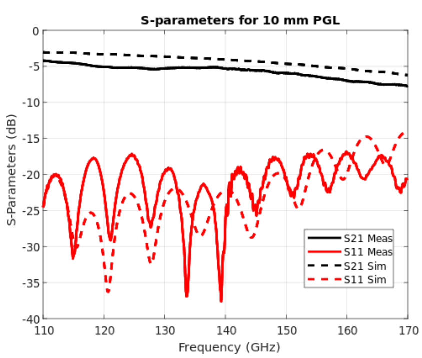
(a)



(b)



(c)



(d)

Fig. 5. Measured and simulated results for PGLs on glass substrate (a) Measured S11 for PGLs with different lengths (b) Measured S21 for PGLs with different lengths (c) Calculated loss per millimeter (d) Model-hardware correlation for 10 mm PGL

The comparison between simulated results and measurement results for 10 mm PGL are also presented in Fig. 5d which shows good model-hardware correlation. The measurement result shows 0.12 - 0.15 dB/mm more loss compared with simulation result, which can be explained by the roughness of the edges of the PGLs. The electrical field concentrates around the metal strip, the edge roughness can introduce more loss to the transmission.

C. *Performance comparison*

The electrical performance of fabricated PGL is compared with other commonly used interconnects on glass substrate in D-band in Table 1. The fabricated PGL shows comparable performance from 110 GHz to 170 GHz. With simpler structures than microstrip, CPW or SIW, PGL shows great potential as D-band interconnects on glass interposer for longer distances.

Table 1. Comparison among interconnects on glass substrate in D-band

Structures	Loss (dB/mm)		
	110 GHz	140 GHz	170 GHz
Microstrip line[2]	0.24	0.43	0.66
CPW[2]	0.27	0.25	0.46
SIW[3]	0.50	0.50 - 0.80	0.72
PGL (this work)	0.22	0.32	0.43

IV. Conclusion

In this paper, the integrated low-loss planar Goubau line (PGL) is demonstrated on glass interposer for D-band interconnects. The proposed PGL uses CPW-PGL launcher to excite the surface wave mode. The stack-up consists of a 200 μm AGC ENA1 glass core with 15 μm ABF GL102 layers laminated on both sides. Semi-additive patterning process (SAP) was used to fabricate the PGL. The measurement for the PGLs with different lengths has been done from 110 GHz to 170 GHz (D-band). The insertion loss of PGL varies from 0.22 – 0.43 dB/mm. With comparable performance and simple structure, PGL can be a promising alternative interconnect on glass interposer for the next generation of wireless communication.

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